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MORPHOLOGICAL CHARACTERISTICS OF THE
BIOLOGICAL ACTION PRODUCED BY MAGNETIC FIELDS

by

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13. ABSTRACT

The author presents a literature survey on the biological action of magnetic fields and the results of experimental-morphological investigations, carried out at his laboratory. As demonstrated, direct magnetic field, 7,000 oersted in intensity, and an indirect on (50 cycles per sec.), 200 oersted in intensity possessed a marked biological effect. In the mentioned physicial conditions and an equal exposure (6½ hours) the indirect field proved to be more active. Direct and indirect magnetic fields proved to induce disturbance of hemodynamics and lymph circulation. Histological investigations demonstrated a paretic dilatation of capillaries, edema of the lungs and of the testicles. Dynamic investigations pointed to normalization of morphological picture 30 days after the field action.
The magnetic fields (direct and indirect) failed to depress the regeneration.

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The development of science in the late 19th and early 20th centuries was characterized by particular progress in the area of physics. The progress of science is followed like a shadow by the appearance of ever newer little-known external physical factors capable of influencing living organisms in general and man in particular.

For example, in connection with the success of nuclear physics, the clear necessity appeared of studying the biological influence of ionizing radiation, and in connection with technical factors, the question of the biological effect of low frequency electromagnetic fields accompanying the operation of charged particle accelerators has been stated anew. If we state the problem more broadly, it is difficult to note an area in which modern technology does not involve magnetic fields of varying intensity. Furthermore, the theoretical prerequisites [9, 35] and certain facts indicate that magnetic fields have a definite significance in physical-chemical reactions, including the metabolic reactions in biological media [4-6, 29-31, 62, 64, 65]. It is quite natural that this new factor attracted the attention of biological researchers in various countries. The biological effectiveness of constant and low frequency (50 Hz) magnetic fields has been studied with the most varied objects both by domestic scientists [ 6, 27, 31, 32, 36, 57-61] and by foreign researchers [67-74, 78, 82, 85], using primarily physiological methods of study. A rather complete review of the literature and interesting observations on the physiological effects of magnetic fields on the organism can be found in the monograph of Yu. A. Kholodov [61].

Also, morphological investigations as a basis for the study of the influence of this factor on the organism have some sense and are doubtless of value for an understanding of certain physiological reactions detected up to the present time.

Morphological experimental studies concerning the entire organism, in spite of the great variations in exposures and intensities of magnetic fields, allow us to provide a general characterization of the changes occurring in animals.

Thirty minutes following the application of a constant and variable EMF (electromagnetic field), all researchers [10-13, 27, 53-55] noted clear indications of disorders of hemodynamics, characterized by paretic expansion of the capillaries. This picture was usually accompanied by fine hemorrhages.

The most detailed morphological studies on the influence of a constant EMF with an intensity of 200 and 7,000 oersteds and the effects of a variable (50 Hz) magnetic field with an intensity of 200 oersteds have been performed in our laboratory. In order to determine the dynamics of the changes, the animals were studied for various times following the last moment of application. The significance of exposure and field intensity were determined.

A variable EMF with an intensity of 200 oersteds and a supply current frequency of 50 Hz, applied for 6-1/2 hours, caused excitation of the animals lasting for approximately one day [10-13, 16].

The signs of disorders of hemodynamics and slight hemorrhage could be macroscopically clearly seen on the serous membranes. Edema of the testicles was quite regularly noted, as well as signs of distellectasis and emphysema in the lungs.


Figure 1. Testicle 12 Hours Following Application of EMF. a, edema of stroma. Hematoxylin-eosine die, × 240; b, vacuolization of nuclei of spermatogenic epithelium, cytolysis. Hematoxylin-eosine die, × 450.

Microscopic studies show that this group of animals always had paretic expansion of the capillaries with edema of the lungs and testicles (Figure 1a).

Comparison of all morphological changes with this comparatively short time of application of the EMF indicated that the "shock" organs are the testicles, in which a variety of changes were observed: in addition to the normal channels, large numbers of channels were always observed, filled with decritus from decomposed cells or with sharply discomplexed epithelium. In estimating the degree of damage to the spermatogenic epithelium, it should be noted that the maximum is found in the differentiated elements, including the spermatozoids and to a lesser extent the spermatogonia. Cytological analysis of the bid spermatogenic epithelium and spermatozoids shows combined changes in the cytoplasm consisting of indications of water metabolism disorders (Figure 1b) with various morphological manifestations of nuclear necrobiosis. The spermatozoids underwent various stages of swelling of the heads right up to formation of the clavate figures described with radiation sickness [52].

The ovaries were found to be less sensitive than the testicles. Here also, however, necrobiotic processes were detected, both in the follicular epithelium, and in the egg cells with various degrees of manifestation (Figure 2).

The determination of nucleic acids (DNA and RNA) in the epithelium of the channels of the testicles showed the complete correspondence of the degree of impoverishment of nucleic acids and the degree of manifestation of necrobiotic changes in the cells. This picture contrasted to the undamaged epithelium, where the quantity and distribution of nucleic acids were normal. The nervous system was also not left intact. The nervous system was also not left intact. In some of the gangliose cells of the subcortical nodes, in the anterior and posterior horns of the spinal column, swelling and vacuolization of nuclei and cytoplasm were observed right up to the formation of "shadow cells."

As concerns the other organs, we must note the presence of hemorrhaging in the lungs and the appearance in the sectors of prismatic crystals of hemoglobinogenic nature, as well as slight destructive changes in the epithelium of the tubules of the kidneys and liver, hyperplasia of the lymph nodes and enrichment of the bone marrow with eosinophils. This reaction of the hemopoietic tissue have also been confirmed by foreign authors. For example, it has been demonstrated that when a constant magnetic field is applied to mice, in 90% of cases hyperplasia of the lymph tissue of the spleen is observed, and 6 hours following removal of the animals from the magnetic field an increase in the cell count in the bone marrow is observed. Application of a permanent magnetic field of 4,200 oersteds for 35 days, with investigation of the material on the 198th day following the application showed the same picture of hyperplasia of the lymph tissue in the spleen with the appearance of a large number of lymphoblasts [81].

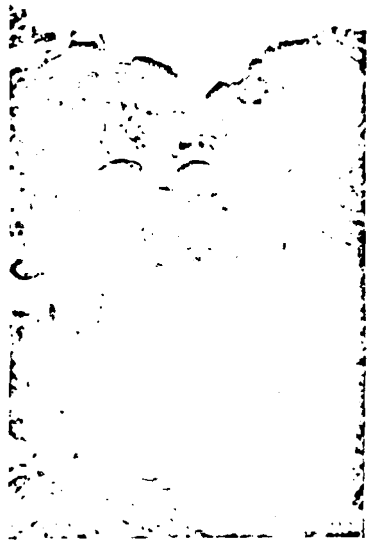

Figure 2. Ovary 1 Day Following Application of EMF. Primordial Follicule Beginning to Develop. Egg Cell With Damaged Nucleus. Hematoxylin-eosine die, × 300.

Our attention is drawn by the enrichment of the tissue of the lungs with mucopolysaccharide material and almost complete loss of tinctorial properties of the agrirophillic substance [12]. Three hours following application of a variable EMF, the content of glycogen in the liver cells was increased [39], but the Rumanian investigators produced contradictory data: they noted a decrease in the content of glycogen in the liver [78], although following brief application of a field.

The studies of T. I. Gorshenina [13] have shown that after 2-4 days, morphological changes remain in the organs studied, but regeneration of the spermatogenic epithelium has begun. The central nervous system shows signs of neuronophagy. The changes in the kidneys become more acute. Macroscopic anemic sectors are seen, and microscopic studies show more widespread macrobiosis of the epithelium, desquamation of the epithelium and formation of unique cylinders, consisting of fragments of cellular cytoplasm. By the 30th day of observation, almost no characteristics of damage can bee seen except for roughening of the agrirophillic substance in the lungs.

This series of experiments has clearly shown the biological activity of a variable magnetic field, also confirmed by experiments with the phagocytic function of the reticular-endothelial system, showing a depression in comparison with a control [33, 49] and an increase in phagocytic activity of the leucocytes for 16 days following application [45].

Repeated application of a variable magnetic field (50 Hz, 200 oersteds) for 24 days once each day with an exposure of 6-1/2 hours and examination 4 hours following the last session [53, 55] showed that the macroscopic picture was

similar. Microscopically, the clearest changes were in the kidneys, testicles, liver and lungs, and changes were less sharply expressed in the other organs.

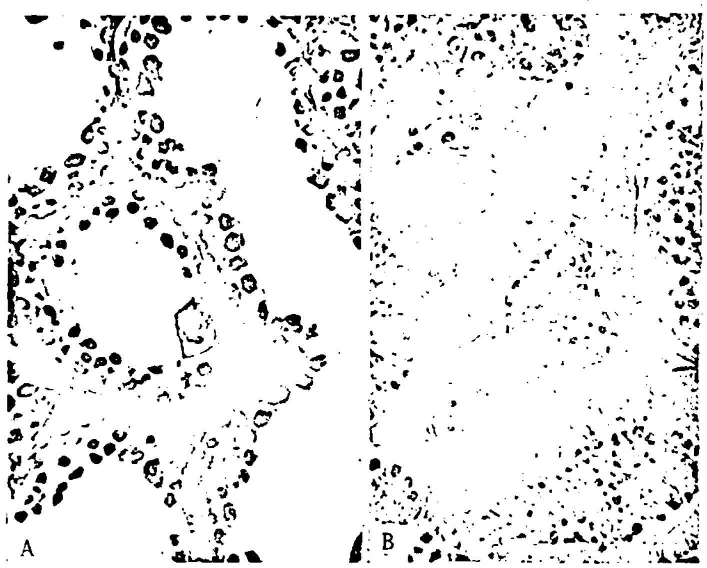


Figure 3. Testicle 1 Day Following Application of Constant EMF (a) and 500 Hours Following Application of Constant Magnetic Field (b). Impoverishment of spermatogenic epithelial cells in channels, necrobiosis of epithelium, gigantic cells. Hematoxylin-eosine die, × 140.

In the kidneys, clear disorders of blood and lymph circulation were combined with clear changes in the epithelial portion of the nephron, which gradually attenuated in the straight tubules and collecting tubes.

In the testicles, the changes were also localized in the zone of differentiated cells and had the same qualitative nature.

Unique destruction of the cytoplasm was detected in the liver and, as was determined by histochemical studies, the problem was disappearance of fat, as well as acid and basic protein [39].

In the lungs, the picture of the changes noted in preceeding observations was repeated but, as in the testicles and other organs, a difference was noted in the quantitative aspect. It should be noted that the indications of disorders of lymph and blood circulation were more clearly manifested than in the experiments with individual 6-1/2 hour application.

The application of a constant magnetic field with an intensity of 200 oersteds and a duration of application of 6-1/2 hours produced basically the same

morphological changes in the structural elements of the organs and tissues, but less clearly expressed, and the recovery processes occurred earlier [14, 15].

We should discuss particularly the group of young guinea pigs, in which the damage to the epithelium of the testicles was quite sharply expressed. Almost complete destruction of all channels was observed (Figure 3a) with the appearance of a large quantity of multinuclear cells, and no signs of regeneration were observed during the period of observation.

A constant magnetic field with an intensity of 7,000 oersteds and an exposure time of 6-1/2 hours caused, following 1 day, changes, the macroscopic and microscopic picture of which was also identical to the changes described during this time following application of a variable field (50 Hz, 200 oersted) with 6-1/2 hours exposure [55].

The effects of the constant magnetic field of 7,000 oersteds applied for 500 hours (12 hours each day for 42 days) [53, 54] were characterized by clearly expressed disorders in hemodynamics and lymph circulation. Polyemia of the internal organ, hemorrhages in the lungs and edema were always encountered, most clearly expressed in the testicles. In these observations, particularly clear changes were found in the testicles, showing not only a variety of morphological changes, but also sharp manifestations and broad extent. Most of the channels were damaged and their open cross sections were filled with cellular decritus. One interesting peculiarity of this group of experiments was the frequent encountering of gigantic cells among the decritus, and sometimes in the channels with preserved epithelium, also in the channels of the appendages (Figure 3b). The number of spermatozoids was either sharply decreased, and they were characterized by indentations of the heads, or they could not be found at all.

In the spleen, with general retention of the structure of the organ and moderate hemosiderosis, in all cases there was an increase in follicules due to accumulation of structurless, weakly oxyfillic mass in their peripheral segments, replacing the cellular elements sometimes almost to complete disappearance. With ordinary dieing methods, this substance was similar to amyloid, but none of the reactions which we know of produced a clear positive result. The lymph nodes and bone marrow were hyperplasic, the bone marrow rich in eosinophils.

This group of experiments also showed certain changes in the adrenals, where the cortical shells sometimes showed a typical mitosis figures and very rare microsectors with signs of necrobiosis. The marrow material showed a picture of perivascular edema and lysis of the nuclei of individual cells. Observations have been published [78], confirming that even brief exposure to a constant magnetic field causes morphological changes in the adrenals, indicating a drop in the function of the central material and an increase in the function of the cortex.

The studies of A. I. Ryzhov [40-42] have showed reactive changes in the nervous system of the gastrointestinal tract and the skin (increased argentophillicity).

As we know, stress on the functions of the organs or systems helps to reveal the action of such physical factors as, for example, ionizing radiation [48]. Similar investigations were performed in a variable EMF (50 Hz, 200 oersted, 6 hours each day for 4 days) under conditions of stressed liver and kidney function, caused by the introduction of chloretics and diuretics to the organism [37-39].

The study showed that under these conditions the necrobiotic changes in the liver were clearly expressed. Changes were also noted in the Kupfer's cells, usually resistant to the effects of magnetic fields during the early periods of application. Not only hypertrophy, but also vacuolization of their nuclei were observed. The RNA were characterized only by diffuse coloration of the fine threads in the cytoplasm. The nucleoli either accepted the die poorly or were not detected at all. The maximum of all these changes was observed by the end of the first day.

In the kidneys without elevated function, the epithelial portion of the nephron was most sensitive to the application of EMF. Following introduction of mercusal, the changes in this portion of the nephron became more clearly expressed and widespread. Following introduction of eufillin, the vascular portion of the nephron was most involved.

The influence of constant and variable magnetic fields on the organ of vision [50, 51] has been studied using considerable material (180 guinea pigs) in its clinical and morphological aspects. These studies have shown that the most clearly expressed changes are noted with the application of variable EMF.

Following a single application of variable EMF with an intensity of 200 oersteds, the animals showed hyperemia of the blood vessels, conjunctive sclerosis, edema of the cornea, most expressed in the center, and a decrease in sensitivity. These vital changes have been confirmed by microscopic investigation, showing vacuolization of the corneal epithelium, edema and defibrillation of its plates. Also, disorders of lymph circulation in the ciliar body, hyperemia of the vascular membrane, hydropic changes in the epithelium of the anterior capsule of the lense, vacuolization in its cortical layers and necrobiosis of individual gangliose cells of the retina were observed. By the 30th day following exposure, all of the changes had become less clearly expressed or disappeared.

When the field was applied for one day, the changes were qualitatively the same, but quantitatively more sharply expressed.

Longer exposure to a variable EMF (24 days of 6-1/2 hours each day) caused greater polymorphism of the clinical and morphological changes.

As concerns a constant magnetic field, both with brief and with longer exposure (7,000 oersteds, 500 hours), the clinical and morphological changes were weakly expressed and in constant.

At the present stage of investigations we can state with some certainty that under the conditions of the magnetic field intensities tested, the patho-

logical changes arising in a number of organs and systems are not catastrophic in nature. These changes increase on the first day, and show weaker signs of progressing with lengthened exposure time. When the exposure to the magnetic fields is stopped, a tendency toward normalization of the structures is observed. However, this factor is far from harmless, particularly for certain particular organs and systems, especially the reproductive glands.

The results presented demand further investigation, and not only in the morphological aspect; a broad prospect is open for studies from the standpoint of the physiology of functions and biochemistry.

There arises in this connection the constant and always difficult question of the pathogenesis of the changes detected. The complex and as yet far from clear cause-effect chain in this new pathology does not as yet allow us to solve this problem, even approximately. However, there is essential significance in the clarification of the nature of the effects of EMF (direct or indirect) on the organism.

Investigations with tissue cultures have shown that EMF influence the process of cellular division. In a noncontinuous magnetic field of low intensity, the growth of a culture of fibroblasts may be increased in comparison with a control culture by 26%, whereas continuous fields of high intensity retard the growth of the culture. During the process of division, anomalies have been noted in the structure of the nucleus, with changes in the type of chromosomes and with multipolar divisions [77], and increase in cellular proliferation, manifestation of a typical and multinuclear cells of gigantic dimensions, defibrillation [85]. Furthermore, the EMF have a cytonecrobiotic effect on tumorous cells [18].

We must discuss the work performed in this direction by Delorenzi [76, 77]. They were begun in 1935. The author returned to his old materials in 1961, in order to test the results produced earlier with modern optical instruments. His investigations were directed toward detection of the morphological anomalies of the mitotic process. He discovered the phenomenon of halting of mitosis upon transition from the anaphase to the telophase. This creates the impression of an increase in the number of mitoses, since when the total mitotic coefficient is counted, mitoses stopped in development are included. Quite frequently, the fission of the nucleus is not accompanied by cellular division, thus forming two-nucleus, and frequently multinuclear cells. Furthermore, fission of nuclei by amitosis is observed. During the prophase and metaphase, the effects of the magnetic field are particularly clearly reflected in the nuclear chromatin. The chromosomes are subject to various changes which prevent further development of the mitotic process. For example, merging of chromosomes into more or less large accumulations which then divide into individual chunks is observed, the chunks later being subject to lysis. Fluctuations in the degree of migration of chromosomes and multipolar mitoses in the cells were frequently obser ed [76, 77].

When placed in a magnetic field with an intensity of 5,000 oersteds, cultures of the tissue of the heart of a 9 day chick embryo, following 3 to 6 hours exposure, showed changes only of the cytoplasm [87]. A magnetic field with an intensity of 1,200 oersteds had no influence on the growth of hela of cells in the tissue culture [80].

Two trends have been noted in the theoretical foundation of the mechanism of the action of a magnetic field up to the present time. According to the first, older idea, the effect of a magnetic field on an organism is manifested through its nervous system. This idea was stated as early as 1780 in a report to the French Royal Medical Society concerning studies performed by Mesmer [16].

The effects of magnetic fields directly on the nervous system were reported in later studies as well [16, 17]. One common feature for these works is the statement that the mechanism of the action of the magnetic field can be reduced to the induction of an electric current in the nerve as in a conductor.

A number of works of recent times indicate the possibility of direct action of the magnetic field on the brain [46, 66]. When a magnetic field acts on the diencephalon of the frog, the phenomenon of Sechenov inhibition is observed. It has been detected in fish by the method of conditioned reflexes that perception of a magnetic field is disrupted by damage to the diencephalon [57, 60].

Morphological studies in this direction [1, 2] have shown that earliest of all under the influence of a constant magnetic field are the productive-distrophic disruptions of the neuroglia, but since the glial formations are distinguished by high metabolism, the effects of a constant magnetic field on the brain may be realized to a significant extent through changes in the metabolism of the neuroglia.

Another trend brings up the question of the direct electromagnetic effect on living material other than the nervous system and is characterized by the use of methods of modeling and mathematical analysis.

Historically, the earliest work in this trend is the work of P. V. Savostin [43], who distinguishes the chemical and physical aspects of the influence of a magnetic field. The chemical aspect is found in the fact that the cell elements (Fe, Mn, $O_2$) taking part in oxidation are paramagnetic, while those which take part in oxidation are diamagnetic. The interaction between magnetic elements is accelerated. Since the former are better magnetized in a magnetic field, consequently, processes of oxidation are accelerated.

"In addition to the chemical effect, the effects of a magnetic field should include another, purely physical element related to an increase in friction between the protoplasm and the cellular envelope resulting from changes in the paths of the plasmatic charge-carrying particles" [43]. The statements of P. V. Savostin concern plant tissue.

It has been found in recent years that the effects of the magnetic field cause the equilibrium of chemical reactions to be displaced in the direction of the formation of materials with great paramagnetism as a result of the accumulation of free radicals. Calculation of the changes in concentration of materials in a solution under the influence of a magnetic field have shown that this change is too little to be detected using physical and chemical methods. However, it is assumed that it can have a biological effect, changing the rates of chemical reactions [83, 84]. It is known that all materials in the organism

have various values of magnetic susceptibility, represented by the diamagnetic or paramagnetic states [19, 20, 22-27, 43]. It has been experimentally proven that the magnetic properties of materials can be changed by physical factors of the medium: temperature, pressure, external magnetic field intensity [20, 32], and also (in biological objects) by the physical state [7, 8, 44, 48, 75, 88]. In order to explain the degenerative changes in cells observed in a culture, it was assumed that a magnetic field is capable of influencing the magnetic properties of the "chemical components" of the cell, thus disrupting the "fine" equilibrium (chemical or other) within and without the cells [31, 32, 86].

Based on changes in the movement of ions and the movement of dipolar molecules in solutions under the influence of a magnetic field, the belief has been stated that the regular displacement of ionized metabolyte radicals in a magnetic field can also be disrupted. This leads to changes in their concentration and diffusion, which cause disruption from the strictly organized process of synthesis [81].

Thus, the contemporary concept of the direct action of a magnetic field on the organism consists of changes in the magnetic properties and disruption of the motion of charged particles in the cells of the tissue. This in turn is manifested as disruption of tissue metabolism.

As we can see from the literature data presented, science has accumulated a sufficient quantity of facts indicating the effectiveness of the action of variable low frequency and constant magnetic fields both on the structural elements of living systems and on the organism as a whole. Only individual works negate the possibility of the influence of a magnetic field [7, 34, 56, 79].

These studies have been characterized by the application of various methods for production of variable and constant artificial magnetic fields, the intensity and exposure of which was varied over broad limits. Most probably, this can explain the contradictory nature of some of the results produced.

It should be noted that most of the works are empirical in nature. Theoretical foundations for the facts accumulated are either completely missing or are simply proposed. Only a few individual authors, based on the methods of modeling and mathematical analysis, have made attempts to explain the mechanism of action of low frequency magnetic fields [3, 8]. All of this doubtless indicates the complexity of the problem as a whole.

In recent years, interest in the problem of the influence of magnetic fields on living organisms has increased significantly. In addition to the large number of works appearing in print, this is also indicated by the symposia held in 1961-1962 and 1966 in the USA and in 1963, 1965 and 1966 in the Soviet Union. Centers of information on this problem have been set up by resolutions of these symposia [72].

The biological effects of low frequency magnetic fields are one of the most important problems in biophysics at the present time.

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